Chapter 10

Sound Waves: Characteristics and Applications

Redeveloped Edition | Class 9 Science | IESC Series

Original NCERT content reimagined with everyday life examples, creative AI-enhanced exercises, and interdisciplinary insights.

Opening Wonder

It is 7:40 a.m. You are squeezed into a share-auto on the way to school, earphones in, volume just loud enough to drown out the honking outside. Somewhere behind you, a temple bell rings out for the morning aarti. A truck driver leans on his horn. Your friend, sitting shoulder to shoulder with you, says something — you see her lips move, but between the honking, the bell, and the song in your ears, you have no idea what she said.

Now pause. In that one chaotic second, at least four completely different sounds — horn, bell, voice, music — arrived at your ears **at the same time**, travelling through the same air, without smashing into each other or turning into noise-soup. Your brain somehow pulled them apart and even let you recognise your friend's *voice* specifically, buried inside the honking.

How does that even work?

What actually *is* sound? You already know from Chapter 7 that sound is a form of energy, and that energy is never created or destroyed — only converted from one form to another. So which form of energy became sound when that horn blared? How did it *travel* nearly ten metres through moving traffic to reach your eardrum? And why can a dog hear a hidden whistle that your ears cannot detect at all, while a doctor can "see" inside a pregnant woman's womb using sound no human ear can hear?

This chapter is about answering exactly these questions — how sound is born, how it moves, what makes one sound different from another, and how humans have learned to bend sound to their will: to scan unborn babies, break kidney stones without surgery, find shipwrecks on the ocean floor, and cancel out the roar of a jet engine inside your earphones.

10.1 Production of Sound — Vibrations Everywhere

Every sound you have ever heard — a dhol at a wedding baraat, the *azaan* from a mosque loudspeaker, your phone's ringtone, the screech of a metro train's brakes — began the same way: **something vibrated.**

Vibration is the periodic to-and-fro motion (oscillation) of an object. Pluck a stretched string, strike a metal plate, or blow air through a hollow pipe, and the object begins to vibrate rapidly back and forth. That rapid vibration disturbs the air (or whatever medium surrounds it) and is heard by us as sound. The vibrating object is called the **source** of the sound.

Musical instruments make this obvious: a guitar or *sitar* string vibrates when plucked, a *tabla* membrane vibrates when struck, and a *bansuri* (flute) produces sound because

the column of air trapped inside the hollow pipe vibrates when you blow across its opening. In most instruments, more than one vibrating part works together — the string of a *sarangi* vibrates, and so does the wooden body around it, shaping the final sound.

Activity 10.1 & 10.2 — Redeveloped: Feel the Vibration

Original book version: Pluck a rubber band stretched across an open cardboard box; strike a tuning fork against a rubber pad.

Everyday version: Take an empty *dabba* (steel tiffin box or biscuit tin) with its lid removed, and stretch two or three rubber bands across the open mouth — the kind used to tie vegetables at the sabzi mandi work perfectly.

Try this:

1. Pluck one rubber band gently with a finger. Do you hear a sound? Is the band visibly vibrating?

2. Wait until the band completely stops moving. Does the sound stop at exactly the same moment?

3. Stretch the band tighter (higher tension) and pluck again. Then loosen it and pluck again. Does the sound change?

4. Now take the rubber band off the tin entirely, stretch it between two fingers near your ear, and pluck it. Is the sound still produced? Is it as loud as before?

What you should notice: as long as the band is stretched and vibrating, you hear sound — the instant the vibration stops, the sound stops too. This confirms: **sound is produced by vibrations**, and the tin (like the wooden body of a *sitar*) makes the sound louder by amplifying the vibration through a larger surface, not by producing the sound itself.

Bonus — the tuning fork version: If you have access to a tuning fork, strike a prong gently against a soft rubber pad (never against a hard surface — it can damage the fork) and bring it near your ear. Then touch the vibrating prong to the still surface of a bowl of water. You will see ripples form — visible proof that the metal prong is physically oscillating, even though your eye cannot see the vibration directly in air.

Everyday Connection: Your Own Voice Box

While talking or singing, gently place two fingers on your throat, over your *larynx* (voice box). Do you feel a buzzing vibration? That buzz comes from your **vocal cords** — tightly stretched muscular flaps inside the larynx that vibrate as air from your lungs rushes past them. Your tongue, lips, mouth, and nasal cavity then shape that raw vibrating sound into recognisable speech, song, or a scream during a cricket match six.

This is exactly what happens every time you record a WhatsApp voice note: your vocal cords vibrate, the phone's microphone senses the resulting air vibrations, and converts them into an electrical (and then digital) signal that your friend's phone turns back into sound.

Thread of Curiosity: A Village Where Your Name Is a Tune

In **Kongthong**, a village near Shillong in Meghalaya — nicknamed the

"Whistling Village" — every person is given a unique *tune name* at birth, composed by their mother as a lullaby. Instead of calling out a word, villagers whistle or sing each other's tune to call them home across the hills. This tradition is called **Jingrwai lawbei**. It is a striking reminder that the vibrating source of sound (here, a whistled tune from the human mouth) can carry as much identity as a spoken name.

10.2 Propagation of Sound — Sound Needs a Medium

Sound is produced by a vibrating source, but how does it actually *reach* your ear from metres — sometimes kilometres — away? Does it only travel through air, or can it move through solids and liquids too?

Activity 10.3 & 10.4 — Redeveloped: Sound Through Solids and Liquids

Original book version: Knocking on a desk; tapping spoons underwater in a bucket.

Everyday version — the hostel wall trick: Ask a friend to gently scratch or tap on one end of a long steel almirah (cupboard) or a wooden study table while you listen with your ear in the air a metre away — you'll barely hear it. Now place your ear directly against the almirah or table (covering your other ear) and ask them to tap again. The sound is suddenly much clearer and louder. **Sound travels through solids too — often better than through air.**

Everyday version — the water bottle trick: Fill a large steel *matka* or bucket with water. Tap two metal spoons together in air first and note the sound. Now submerge both spoons fully in the water (without touching the sides) and tap them again. You still hear the clinking — proof that the sound travelled from the spoons, through the water, then through the air, and finally into your ear. **Sound travels through liquids as well.**

Put together, these two mini-experiments show that sound can propagate through **solids, liquids, and gases** — collectively called the **medium**.

10.2.1 Sound Needs a Medium to Propagate

But what if there is *no* medium at all — a **vacuum**, a space with no matter? A classic demonstration answers this: an electric bell is placed inside a sealed bell jar and switched on. As a vacuum pump gradually removes the air from the jar, the sound of the bell becomes fainter and fainter, until — once a near-vacuum is reached — almost no sound is heard at all, even though you can still *see* the bell's hammer striking. Let air back into the jar, and the sound returns, growing louder as the air density increases again.

This tells us something fundamental: **sound cannot propagate through a vacuum.** It absolutely needs a material medium — solid, liquid, or gas.

Everyday Connection: Why Astronauts on a Spacewalk Can't Simply Talk

Outer space is (almost) a vacuum. Two astronauts repairing the exterior of a space station during a spacewalk are floating just centimetres apart from each

other, yet if one of them tapped a wrench against the metal hull, the other would hear **absolutely nothing** directly through the space between their suits — no medium, no sound. This is why astronaut suits are fitted with radio microphones and speakers: astronauts communicate using radio waves (which, unlike sound, do not need a medium and travel fine through vacuum), not by shouting.

India now has direct interest in this question — ISRO's **Gaganyaan** mission is being developed to send Indian astronauts (*vyomanauts*) into orbit for the first time. Every one of their spacesuit communication systems has to be engineered around this exact physics: no medium, no sound, only radio.

10.3 Sound Waves — Compressions, Rarefactions, and Longitudinal Motion

We now know sound needs a medium — but *how* does it actually move through that medium? A vibrating source, in general, sends sound outward in every direction depending on its shape. For simplicity, physicists usually consider sound as moving along a single direction, the way it would inside a long tube.

Activity 10.5 — Redeveloped: The Slinky Model

Original book version: Stretch a slinky spring toy between two people; give one end a sharp push-and-pull.

Everyday version: Slinky toys are sold at almost every fair (*mela*) and toy shop in India — borrow one, or use a long soft spring. Mark one coil with a sketch pen. Lay the slinky flat on the floor or a long table. Ask a friend to hold one end fixed while you hold the other, keeping it slightly stretched.

Give your end a sharp push toward your friend, then pull it back quickly. Watch closely — you'll see a disturbance (a place where the coils bunch up close together) travel down the slinky toward your friend, even though **the marked coil itself only moves a little back and forth and returns to roughly where it started.**

Now push and pull your end repeatedly, quickly, over and over — simulating continuous sound production. A whole series of bunched-up and stretched-out regions travels down the slinky one after another.

The key insight: the disturbance travels the full length of the slinky, but no single coil actually travels with it — each coil just oscillates about its own resting position. Sound in air behaves exactly like this.

Now imagine a long tube filled with air, with an oscillating piston at one end. When the piston is at rest, the air inside has a uniform, *average* density. As the piston moves forward, it pushes air particles closer together in the region just ahead of it — increasing the density there. This region of higher-than-average density is called a **compression (C)**. As the piston then moves backward, it pulls particles apart, creating a region of lower-than-average density called a **rarefaction (R)**.

The compressed particles push against their neighbours further ahead, passing the compression forward through collisions — even though no single air particle travels the length of the tube. As the piston oscillates continuously forward and backward,

alternating compressions and rarefactions are produced one after another and these disturbances propagate outward from the source.

A sound wave, therefore, is a disturbance consisting of a series of alternating compressions and rarefactions that propagate through a medium, without any actual bulk flow of the medium's particles. The direction in which the wave travels is called the direction of propagation.

Because the particles of the medium vibrate **parallel** to the direction in which the wave itself travels, sound is classified as a **longitudinal wave**. (This is different from a **transverse wave** — such as light, or the ripple you saw on the water surface in Activity 10.2 — where particles vibrate *perpendicular* to the direction of wave travel.) Since a sound wave absolutely requires a material medium to exist, it is also classified as a **mechanical wave**.

Everyday Connection: The Stadium Wave at a Cricket Match

You've almost certainly seen — or done — a stadium "Mexican wave" during a cricket match: one section of spectators stands up and sits back down, and a moment later the *next* section does the same, so a visible ripple of standing-and-sitting races around the entire stadium in seconds.

Notice something important: **no single spectator actually runs around the stadium** — you stand up, sit down, and stay in your own seat the whole time. Only the *pattern* of standing travels. This is precisely the idea behind wave propagation in a medium: the disturbance travels; the particles (or, here, the people) mostly stay where they were, just oscillating briefly about their normal position. (The stadium wave is technically closer to a transverse motion, since spectators move up-and-down while the wave races sideways around the stadium — but the core lesson, that the wave and the particles are not the same thing, is exactly the one you need for sound.)

Ready to Go Beyond: Why Diwali Crackers Go BANG and Not Just "Fizz"

When firecrackers explode, or lightning triggers a clap of thunder, the sound is produced slightly differently from a vibrating string. Hot gases are released or heated so rapidly that they expand almost instantaneously, slamming into the surrounding air and creating a sudden, sharp disturbance in air density that radiates outward as a loud pulse. A very similar — but far more intense — disturbance is produced when a supersonic aircraft flies faster than the speed of sound itself, creating what is called a **sonic boom**.

This is also why sound spreads out from a small firecracker equally in every direction as a **spherical wave** — imagine invisible expanding balloons of compression and rarefaction racing outward from the point where the cracker burst, reaching every listener nearby at almost the same loudness (before naturally growing fainter with distance).

10.4 Energy of Sound Waves

If sound is just density disturbances travelling through a medium, does it actually carry anything real and useful — or is it purely a pattern with no physical effect? The answer: **sound carries energy**, and that energy can visibly move objects.

Activity 10.6 — Redeveloped: Dancing Rice Grains at a Garba Speaker

Original book version: Stretch a rubber/cellophane sheet over a wide container, sprinkle grains on top, and produce a loud sound nearby.

Everyday version: Stretch a piece of a burst balloon tightly over the open mouth of a steel *katori* (bowl) or a wide glass, securing it with a rubber band, like a small drum. Sprinkle a thin, even layer of dry rice grains or semolina (*sooji*) on top.

Now, without touching the bowl, hold a phone speaker playing loud bass-heavy music (or bang a thali with a spoon) close to — but not touching — the stretched sheet. Watch the grains.

What you'll observe: the grains visibly jump and dance, even though nothing physically touched the bowl. Try it again with the volume turned down, and then up — do the grains jump higher when the sound is louder?

Why this happens: the sound wave travelling through the air reaches the stretched membrane and makes it vibrate, and this vibration flings the grains upward. This is the same reason you can literally *feel* the bass thump against your chest standing close to a large speaker at a wedding *baraat* or Navratri *garba* — sound energy is physically pushing the air (and you) around.

When a source vibrates, it transfers energy to the surrounding medium. As the sound wave propagates, the vibration of particles and their collisions with neighbouring particles carry that energy forward — **it is the energy that is transferred, not the particles of the medium themselves.**

Everyday Connection: Mic to Speaker — Energy Changing Costumes

A **microphone** — whether inside your phone, a wireless collar mic on your teacher, or a stage mic at a school function — converts sound energy into electrical energy. Sound waves reaching the mic make a thin membrane called a **diaphragm** vibrate, and this vibration is converted into an electrical signal.

A **speaker** does exactly the reverse: an electrical signal makes a diaphragm or cone inside the speaker vibrate, which produces sound once again. Every time you play a song from your phone through Bluetooth earphones, sound energy has been converted to electrical energy, then to a wireless digital signal, then back to electrical energy, and finally back into sound energy — all in a fraction of a second, close enough to your eardrum that you don't notice the relay race at all.

10.5 Graphical Representation of a Sound Wave

As a sound wave travels, the density of the medium at any given instant varies periodically with distance from the source. If we plot this — distance along the x-axis, density of the medium along the y-axis, with the average density marked as a horizontal dashed reference line — we get a wave-shaped graph.

In the region of a compression, density rises above average, reaching a maximum at what is called the **crest** of the graph. In the region of a rarefaction, density falls below

average, reaching a minimum at what is called the **trough**. The density then rises again, and the whole pattern repeats.

> **🎵 Everyday Connection: You Already Read Sound Graphs Every Day**
>
> Open WhatsApp and look at any voice note you've sent or received. That squiggly bar pattern shown along the message bubble is a real graphical representation of a sound wave — technically plotting how the loudness (amplitude) of the recording changes over time. Music apps like Spotify, YouTube, and voice recorder apps all display similar waveforms. When you scrub your finger along that waveform to skip to a louder or quieter part of a voice note, you are literally reading a graph of density-like variations, exactly like Fig. 10.16 in the original textbook — just measuring amplitude over time instead of density over distance.

10.6 Characteristics of a Sound Wave

10.6.1 Wavelength, Frequency, and Time Period

The distance between two consecutive crests (or two consecutive troughs) is called the **wavelength** of the wave, represented by the Greek letter λ (lambda). Its SI unit is the **metre (m)**.

At any single fixed position in the medium, the density keeps oscillating — from maximum (crest) to minimum (trough) and back to maximum again. One complete cycle of this change is called **one complete oscillation**. The number of such oscillations occurring at a fixed point per unit time is called the **frequency** of the sound wave, represented by the Greek letter ν (nu). Its SI unit is per second (s^{-1}), also called **hertz (Hz)**.

The time taken for one complete oscillation at a fixed point is called the **time period**, represented by T, with SI unit **second (s)**. Time period and frequency are inversely related — a shorter time period means a higher frequency:

$$\nu = 1 / T \qquad \text{... (Eq. 10.1)}$$

Everyday sounds are usually a mixture of many frequencies mixed together. Nearly single-frequency sounds can be produced by a tuning fork, or by whistling.

> **🥁 Worked Example 10.1 — Redeveloped: Counting a Dholki's Beats**
>
> **Original book version:** "If there are 10 density oscillations in 2 seconds at a given position, calculate the frequency and time period."
>
> **Everyday version:** At a wedding *sangeet*, a *dholki* player produces 10 clear beats (density oscillations) of a single note in 2 seconds. Find (i) the frequency, and (ii) the time period of that note.
>
> **Solution:**
>
> frequency = number of oscillations ÷ time taken = 10 ÷ 2 s = **5 Hz**
>
> time period = time taken ÷ number of oscillations = 2 s ÷ 10 = **0.2 s**
>
> Every beat, therefore, repeats once every 0.2 seconds — five times a second.

🧵 Thread of Curiosity: Turning Your Phone into a Sound Lab

Free apps such as **Phyphox** can detect and graphically display the frequency of any sound in real time using your phone's microphone (look for the "Audio Spectrum" or "Audio Scope" tool). If your teacher sets this up as a classroom activity, try singing the Indian classical *swaras* — Sa, Re, Ga, Ma, Pa, Dha, Ni, Sa — one after another and watch the frequency reading rise step by step: **Sa** has the lowest frequency, and each subsequent note is progressively higher, until the upper **Sa** — exactly double the frequency of the starting Sa. Try comparing your own voice's frequency for a note against a friend's, or against a tanpura drone app — do boys' and girls' voices show a clear frequency difference for the same note?

10.6.2 Amplitude and Intensity of Sound Waves

The **amplitude** of a sound wave is the maximum change in the density of the medium in a compression (or rarefaction), compared to the average density. A larger change in density means a larger amplitude — and a larger amplitude carries **more energy**. This is exactly why, in Activity 10.6, striking the thali harder made the grains jump higher — more energy was transferred to the particles of the medium, causing bigger vibrations of the stretched sheet.

The amount of sound energy passing through a unit area, perpendicular to the direction of propagation, per unit time, is called the **intensity** of sound. As a sound wave spreads outward from its source, the same total energy is distributed over an ever-larger area (imagine an expanding sphere around a firecracker) — so intensity **decreases with distance** from the source, even though the total energy is conserved. Sounds that start out with a larger amplitude carry more energy and can therefore travel further before their intensity fades to nothing.

🌍 Everyday Connection: Front Row vs. Back Row at a Concert

Ever notice how the bass at a live concert or DJ set feels overwhelming in the front rows, right next to the speaker stack, but is a gentle background thump if you're standing at the very back? Same source, same amplitude at the speaker cone — but the sound energy has spread over a much larger area by the time it reaches the back, so its **intensity** there is much lower. This is also exactly why standing near a busy flyover in your city exposes you to far more sound energy than someone in a park 500 metres away — distance from the source is one of the simplest and most effective ways to reduce your exposure to noise.

10.6.3 Speed of Sound

The speed of sound describes how fast the density disturbance itself — the compressions and rarefactions — moves through a medium. It can be defined as the distance travelled by a point on the wave, such as a crest or a trough, in unit time.

For a wave of a given frequency, the distance between two consecutive crests is one wavelength (λ), and this distance is covered in one time period (T). Therefore:

> speed = distance ÷ time $\implies$ $v = \lambda / T$

Since $\nu = 1/T$ (Eq. 10.1), this becomes the single most important equation in this chapter:

> $v = \lambda \times \nu$ ... (Eq. 10.2) (speed = wavelength × frequency)

The speed of sound depends heavily on the **medium** through which it travels — it moves fastest through solids, slower through liquids, and slowest through gases. Sound typically travels about 4–5 times faster in water than in air, and 15–20 times faster in solids than in air. In air specifically, speed also depends on **temperature and humidity** — the speed of sound in dry air is about **331 m/s at 0 °C** and rises to nearly **344 m/s at 22 °C**. Increasing temperature or humidity increases the speed of sound.

State	Substance / Medium	Approx. speed at 15 °C
Solid	Steel	5000 m/s
Liquid	Water	1500 m/s
Gas	Air	340 m/s

Worked Example 10.2 — Redeveloped: The Range of Your Earphones

Original book version: "Human hearing roughly spans 20 Hz to 20 kHz. Find the corresponding wavelengths in air for these two frequencies, using speed of sound = 344 m/s."

Everyday version (numbers preserved exactly, as they matter for real earphone design): The full range of human hearing is 20 Hz to 20,000 Hz. Find the wavelength in air, at 344 m/s, corresponding to each end of this range — the very range your earphone drivers are engineered to reproduce.

Solution: Using $v = \lambda\nu$, we rearrange to $\lambda = v / \nu$.

For $\nu = 20$ Hz: $\lambda = 344 \text{ m/s} \div 20 \text{ s}^{-1} =$ **17.2 m**

For $\nu = 20{,}000$ Hz: $\lambda = 344 \text{ m/s} \div 20{,}000 \text{ s}^{-1} = 0.0172$ m = **1.72 cm**

Why this matters for your earbuds: the lowest bass note you can hear has a wavelength longer than your classroom, while the highest treble note has a wavelength shorter than your thumb. This enormous range (a factor of 1000!) is exactly why earphone engineers must design tiny drivers that can still reproduce deep, room-sized bass waves — a genuinely difficult acoustic engineering problem.

Worked Example 10.3 — Redeveloped: Timing a Monsoon Thunderstorm

Original book version: "Lightning is seen before thunder is heard because sound travels slower than light. If the delay is 5 s, estimate the distance to the strike (speed of sound = 340 m/s; light considered instantaneous)."

Everyday version: During a Mumbai monsoon storm, you see a flash of lightning outside your window and, five seconds later, hear the crack of thunder. Roughly how far away did the lightning strike?

Solution: distance = $v \times t = 340 \text{ m/s} \times 5 \text{ s} =$ **1700 m (1.7 km)**.

Quick trick: since light reaches you almost instantly compared to sound, you can count "one-elephant, two-elephant..." from the flash to the thunder, divide

by 3, and get the distance in kilometres — a genuinely useful, physics-backed way to estimate how close a storm is.

Worked Example 10.4 — Redeveloped: A Railway Fence in Steel

Original book version: "From a graphical representation of a sound wave in steel with wavelength 50 m, find its frequency and time period if the speed of sound in steel is 5000 m/s."

Everyday version: A long steel guard-fence runs alongside a railway track. A sound wave travelling through the steel fence has a wavelength of 50 m. Given the speed of sound in steel is 5000 m/s, find its frequency and time period.

Solution: Using $v = \lambda\nu$, rearranged: $\nu = v / \lambda = 5000 \text{ m/s} \div 50 \text{ m} =$ **100 Hz**

Using $\nu = 1/T$, rearranged: $T = 1/\nu = 1 \div 100 \text{ Hz} =$ **0.01 s**

Ready to Go Beyond: If Speed Depended on Frequency…

In most everyday media like air, the speed of sound depends only on the medium (and its temperature/humidity) — **not** on the frequency or the source producing it. If the source's frequency changes, only the wavelength changes; the speed stays fixed. But imagine, just for a moment, that the speed of sound in air *did* depend on frequency. High notes from a violin would then race ahead of low notes from a tabla, arriving at your ear at different times even if played simultaneously — a concert would sound like a garbled mess, with different instruments constantly drifting in and out of sync depending on distance from the stage. Some engineered materials, such as porous acoustic foams, actually do behave this way — which is one reason such materials are so useful for shaping sound deliberately inside recording studios.

10.6.4 Human Perception of Sound — Pitch and Loudness

Wavelength, frequency, time period, amplitude, and speed are all well-defined, measurable physical properties of a sound wave. But how a sound is *experienced* by a listener is described using different, more subjective terms: **pitch** and **loudness**.

Pitch is how frequency is perceived. Shrill sounds — a whistle, a siren — are said to have a high pitch, corresponding to high frequency; deep sounds — thunder, an aircraft's rumble — have a low pitch, corresponding to low frequency (though the exact mathematical relationship between pitch and frequency is complex).

Loudness is how amplitude is perceived. Sounds with larger amplitude are heard as louder; loudness also naturally decreases as you move further from the source. In everyday language, "loudness" and "intensity" are often used as if they mean the same thing, but intensity is an objectively measurable physical quantity, while loudness depends on the listener's own hearing.

Everyday Connection: The Hearing Range and Your Earphones' Noise Cancellation

The human audible range is **20 Hz to 20,000 Hz (20 kHz)** — though this

shrinks as we age. Waves below 20 Hz are **infrasonic**; above 20 kHz are **ultrasonic**. Humans cannot hear infrasound or ultrasound, but dogs, cats, bats, and dolphins can detect ultrasound, and elephants can detect infrasound (which is part of why dogs sometimes react to sounds — like an approaching earthquake tremor or a distant firework — well before humans notice anything).

Active Noise Cancellation (ANC), found in many popular earphones today, exploits exactly this science of amplitude and waves. A tiny microphone on the earphone picks up the ambient noise wave (like a droning aeroplane engine or an AC hum), and the earphone's circuit generates an *inverted* version of that exact wave — a compression exactly where the intruding noise has a rarefaction, and vice versa. When the two waves combine at your eardrum, they largely cancel each other out (this is called **destructive interference**), leaving your music audible with the background hum dramatically reduced. It is genuinely one of the most elegant everyday applications of wave physics.

Everyday Connection: Decibels and India's Noise Pollution Problem

Loudness is commonly measured on the **decibel (dB)** scale. Rustling leaves measure only a few dB; normal conversation is roughly 60 dB; a bursting firecracker can exceed 100 dB. Because the decibel scale is logarithmic, even a small rise in the dB number represents a **much larger** increase in actual sound intensity.

Indian cities regularly rank among the noisiest in the world, largely from traffic, construction, and festival loudspeakers. India's Central Pollution Control Board sets ambient noise limits that are considerably lower for residential areas (roughly 55 dB in the day and 45 dB at night) and lower still for "silence zones" near schools and hospitals — a rule directly motivated by the fact that **prolonged exposure to loud sound can permanently damage hearing.** Unwanted or harmful sound of this kind is called **noise**, and noise pollution is now recognised as a genuine public-health issue, not just an annoyance. Hearing loss can be measured using an **audiogram**, and people with hearing loss may use **hearing aids** — devices built from exactly the same three components as any sound system: a microphone, an amplifier, and a speaker.

Ready to Go Beyond: Two Ears, One Brain, a Built-in GPS

When sound enters your ear, it makes a thin membrane — the **eardrum** — vibrate. Tiny bones amplify this vibration further, and the **cochlea** (a fluid-filled, snail-shaped organ) converts it into electrical signals that race to your brain, which interprets them as sound.

Having **two ears** lets your brain triangulate the direction a sound came from, by comparing the tiny time gap (often less than a thousandth of a second) between when each ear detects it. This is exactly why you can, without even looking, turn instinctively toward a friend calling your name across a noisy school corridor. Not all animals hear this way — snakes and fish sense vibrations through their entire body, while some insects like crickets have ear-like organs located on their legs.

Thread of Curiosity: Why Every Voice, Instrument, and Tabla Sounds Different

A **tone** is a sound of a single frequency, like a tuning fork or a whistle. A **musical note** — like a *tanpura* string or a singer's voice — is actually a combination of a lowest frequency (the **fundamental**) plus higher frequencies called **overtones**, blended together to create a rich, pleasant sound. This is why Indian string instruments such as the *sarangi*, *sitar*, and *veena* often use extra sympathetic strings — purely to enrich this blend of overtones.

Even when a flute, an *ektara*, and a *tabla* all play the same note at the same loudness, each still sounds unmistakably different. This quality is called **timbre**, and it comes from the instrument's shape, material, and construction, which determine exactly which overtones are produced and how strongly. An **octave** is the interval between two notes where one has exactly double the frequency of the other (for example, 200 Hz and 400 Hz).

This is also why your voice sounds different from your friend's, even singing the identical note — not just because of frequency, but because of how your unique throat, mouth, and nasal cavity shape the overtones. (During adolescence, boys' vocal cords lengthen and thicken, vibrating less frequently and "deepening" the voice — which is why a boy's voice changes noticeably around Class 9.)

Meet a Scientist: Sir C. V. Raman — Listening to the Tabla Like No One Before Him

Chandrasekhara Venkata Raman (1888–1970), born in Tiruchirapalli, Tamil Nadu, won India's first Nobel Prize in Science (Physics, 1930) for discovering the **Raman Effect** — the scattering of light as it passes through a transparent medium. But years before that discovery, in the early 1920s, Raman also carried out pioneering acoustic research into Indian musical instruments, publishing papers explaining why instruments like the **tabla** and **mridangam** produce such unusually rich, harmonious, bell-like tones compared to Western drums — tracing it to the way their drumheads are non-uniformly loaded.

Lesson: Raman treated everyday Indian instruments as legitimate objects of rigorous scientific study — proof that world-class physics can begin by paying close attention to something as familiar as a tabla being played in your own street.

Thread of Curiosity: The Secret Black Patch on a Tabla

Look closely at a *tabla* or *mridangam* and you'll notice a black patch at the centre of the drumhead, called the **syaahi** — a paste made of iron filings, starch, and other materials. The syaahi alters how the membrane vibrates, giving these drums a level of precise tonal control and a rich variety of distinct notes rarely matched by other drums in the world — a design refined over centuries, long before anyone wrote down the physics of vibrating membranes.

10.7 Reflection of Sound

Just like light, sound waves bounce off obstacles — solids or liquids — a phenomenon called **reflection of sound**. Sound obeys the same laws of reflection you have already studied for light: the incident and reflected directions make equal angles with the normal to the reflecting surface at the point of incidence, and all three — incident ray, reflected ray, and normal — lie in the same plane. The most familiar example of sound reflection is the **echo**.

10.7.1 Echo

If you shout near a hillside, a cliff, or down a long empty corridor, you may hear your own voice again a moment later — an **echo**. The sound reflects off the hard, distant surface and travels back to you.

Echoes are not heard everywhere. In a small room, reflected sound arrives back too quickly for your brain to separate it from the original sound. Our brain can distinguish two sounds as separate only if the gap between them is **at least 0.1 s**; anything shorter blurs together. This 0.1 s threshold lets us calculate the minimum distance a reflecting surface must be for an echo to be heard at all: at the speed of sound in air (340 m/s), sound covers a distance of

> distance = speed × time = 340 m/s × 0.1 s = 34.0 m

in 0.1 second — but this is the *round trip* distance (to the surface and back), so the **minimum distance for a clear echo is half of this, 17 m.** Echoes are strongest off hard, smooth surfaces; soft surfaces like curtains absorb sound, while rough surfaces scatter it in many directions, both making a clean echo harder to hear.

Worked Example 10.5 — Redeveloped: An Echo in an Empty School Corridor

Original book version: "You clap in an empty corridor and hear an echo after 0.5 s. If the speed of sound in air is 340 m/s, calculate your distance from the wall."

Everyday version: After the last bell, you clap once in the empty school corridor and hear the echo bounce back exactly 0.5 s later. If the speed of sound in air is 340 m/s, how far away is the wall you're facing?

Solution: the sound travels to the wall and back, so:

distance from wall = (v × t) / 2 = (340 m/s × 0.5 s) / 2 = **85 m**

Everyday Connection: India's Own Whispering Galleries

The **Gol Gumbaz** in Bijapur, Karnataka — one of the largest domes in the world — has a famous **Whispering Gallery** running around the inside of its dome. Because of its precise curved geometry, even a faint whisper spoken at one point can be heard clearly, and multiple times over, at points far across the dome — sound reflecting again and again off the smooth interior surface. Similarly, at **Golconda Fort** in Hyderabad, a hand clap at the entrance's Fateh Darwaza can reportedly be heard almost a kilometre away at the highest pavilion — said to have once served as a warning system for the fort's guards. These aren't lucky accidents; they are centuries-old feats of acoustic engineering, built long before anyone had written down the physics of reflection.

10.7.2 Reverberation

In a large hall or auditorium, emitted sound can bounce off multiple walls, ceiling, and floor in quick succession. When these reflections arrive back with a gap of **less than 0.05 s**, they blend into the original sound instead of arriving as a distinct echo — this persistence of sound after the source has stopped is called **reverberation**.

Modern auditoriums and concert halls are carefully architected to achieve just the *right amount* of reverberation — enough to make speech and music sound rich and full everywhere in the hall, without becoming a garbled, muddy mess. Sound-absorbing panels, upholstered seats, and thick curtains reduce excessive reverberation by soaking up sound energy at soft, porous surfaces.

> **Everyday Connection: Why an Empty Classroom Sounds So Different**
>
> Notice how your empty, unfurnished classroom before school starts sounds sharp and echoey, but the same room, packed with 40 students, backpacks, and notebooks, sounds noticeably duller and quieter? Bodies, cloth, and bags absorb sound far better than bare walls and a hard floor, cutting down reverberation. This is exactly why concert halls, movie theatres, and recording studios are lined with fabric panels or foam — and why an empty mandir hall or auditorium sounds so different once the crowd fills in for a function.

10.8 Ultrasonic and Infrasonic Waves, and Their Applications

Sound waves with frequencies **outside** the human audible range are not "wasted" — they have become essential tools across science, medicine, and technology.

Frequency band	Key applications
Infrasonic waves (< 20 Hz)	Detecting earthquakes, volcanic eruptions, and severe storms — these long-wavelength waves travel enormous distances through air and the Earth.
Human audible range (20 Hz – 20 kHz)	Ordinary speech, music, and everyday environmental sounds.
Ultrasonic waves (> 20 kHz)	Medical imaging (ultrasonography); breaking kidney stones into smaller pieces (lithotripsy); ultrasonic welding and cleaning delicate machine parts; detecting defects inside metal blocks (industrial testing); locating objects by their reflected echoes (sonar, echolocation).

> **Everyday Connection: The Ultrasound Scan Every Indian Family Knows**
>
> Almost every Indian family has, at some point, visited a sonography clinic for a pregnancy ultrasound scan — using high-frequency ultrasonic waves (typically 2–15 MHz, far above 20 kHz) to image an unborn baby without any surgery or harmful radiation. The same underlying ultrasonic technology, in different forms, is used to break kidney stones into fragments small enough to pass out of the body naturally (avoiding surgery), and to detect hairline cracks inside metal

beams and welds on bridges, buildings, and railway tracks before they become dangerous — all without cutting anything open.

10.8.1 Echolocation

Bats are nocturnal creatures that fly and hunt in complete darkness without colliding into obstacles. Most bats emit short bursts of ultrasonic waves, which reflect off nearby objects; by carefully sensing the returning echoes, a bat can determine the exact position of obstacles and prey. This ability to locate objects using reflected sound waves is called **echolocation** — also used by dolphins, whales, and some birds for navigation and hunting.

Everyday Connection: Sonar on India's Fishing Boats and Warships

Humans have adapted the exact same principle as bat echolocation into **sonar** (SOund Navigation And Ranging). Ultrasonic waves are sent into water, and the reflected waves are analysed to determine the distance, direction, and speed of underwater objects. Along India's coastline — in Kerala, Gujarat, and Tamil Nadu — commercial fishing trawlers commonly use sonar-based "fish finders" to detect entire schools of fish underwater before casting their nets, dramatically improving catch efficiency. The Indian Navy similarly relies on sonar aboard its ships and submarines to detect other vessels, shipwrecks, and underwater hazards.

The same physical principle, shrunk down, sits in the ultrasonic parking-assist sensors fitted to the rear bumper of most modern cars, silently beeping faster and faster as you reverse closer to an obstacle.

Worked Example 10.6 — Redeveloped: A Fishing Trawler's Sonar Ping

Original book version: "A naval sonar signal sent into seawater returns after 0.90 s. The speed of sound in seawater is 1530 m/s. How far is the object?"

Everyday version: A sonar-equipped fishing trawler off the Kerala coast sends out an ultrasonic ping to check the seabed depth, and the echo returns after 0.90 s. If the speed of sound in seawater is 1530 m/s, how far below is the object (or seabed) reflecting the ping?

Solution: the 0.90 s includes the time for the signal to travel down **and** back, so the one-way time is 0.90 s ÷ 2 = 0.45 s.

distance = speed × time = 1530 m/s × 0.45 s = **688.5 m**

Journey Beyond: Listening to Places We Cannot See

Sound is helping scientists explore far beyond human hearing. NASA's Mars rovers have recorded the very first sounds ever captured on another planet. Oceanographers are timing the travel of distant earthquake-generated sound through seawater to detect tiny long-term changes in ocean temperature linked to climate change. Biologists are analysing the precise buzz frequency of

mosquito wingbeats to identify which species — and which disease risks — are present in an area. Researchers are even listening to the faint crackling sounds produced by microbes in soil to study soil health and biodiversity. As sensing technology keeps improving, sound is becoming an ever more powerful tool for exploring planets, living organisms, and the hidden activity of nature that no human ear could ever catch unaided.

Chapter Summary

Concept	Core idea	Everyday example
Production of sound	Sound is produced by vibrating objects (the "source").	Rubber band on a tin, tabla membrane, human vocal cords.
Propagation / medium	Sound needs a material medium (solid, liquid, or gas) and cannot travel through vacuum.	Ear against an almirah; astronauts on a Gaganyaan spacewalk hearing nothing directly.
Sound waves	Sound is a longitudinal, mechanical wave — a travelling series of compressions and rarefactions; particles oscillate but don't travel with the wave.	A stadium wave at a cricket match; a slinky spring toy.
Energy of sound	Sound carries energy from source to medium, which can be converted to/from electrical energy.	Rice grains jumping on a speaker; microphone-speaker chain in Bluetooth earphones.
Graphical representation	Density vs. distance graphs show crests (compressions) and troughs (rarefactions).	The waveform shown under a WhatsApp voice note.
Wavelength, frequency, time period	λ = distance between crests; $\nu = 1/T$ = oscillations per second (Hz); $v = \lambda\nu$.	Dholki beats; Sa-Re-Ga-Ma frequencies rising on a Phyphox app.
Amplitude and intensity	Amplitude = max. density change; intensity = energy per unit area per unit time; both fall off with distance.	Bass felt strongly in the front row of a concert, faintly at the back.
Speed of sound	$v = \lambda\nu$; fastest in solids, slower in liquids, slowest in gases; rises with temperature/humidity in air.	Counting seconds between monsoon lightning and thunder to estimate distance.
Pitch and loudness	Pitch = perceived frequency; loudness = perceived amplitude (in decibels, dB).	A siren's high pitch vs. thunder's low pitch; noisy Indian traffic exceeding safe dB limits.

Concept	Core idea	Everyday example
Hearing range	Humans hear 20 Hz–20 kHz; below is infrasonic, above is ultrasonic.	Dogs reacting to sounds humans can't hear; noise-cancelling earphones.
Reflection, echo, reverberation	Sound reflects off surfaces; echo = distinct reflected sound (gap ≥ 0.1 s); reverberation = persistence of sound (gap < 0.05 s).	Gol Gumbaz Whispering Gallery; an empty vs. full classroom's acoustics.
Ultrasonic & infrasonic applications	Frequencies outside human hearing are used in medicine, industry, and nature detection.	Pregnancy ultrasound scans; sonar on Kerala fishing trawlers; bat echolocation.

Revise, Reflect, Refine — Exercises

Basic Recall

1. Explain, in your own words, why sound cannot travel through the vacuum of outer space, using the vacuum bell jar experiment as evidence.
2. Define wavelength, frequency, and time period, and write the equation connecting frequency and time period.
3. What is the difference between an echo and reverberation? State the minimum time gap needed to hear each one distinctly.

Apply & Think

4. **(Numeric)** A temple bell produces a sound wave of wavelength 1.7 m travelling through air at a speed of 340 m/s. Calculate (i) the frequency of the sound, and (ii) its time period.
5. Two students, one in Chennai and one in Shimla, both clap once in an empty hall and each hears their own echo. The Chennai student hears their echo after 0.3 s, and the Shimla student after 0.1 s. Which student is standing closer to the reflecting wall, and by roughly how much (assume speed of sound = 340 m/s)?
6. A friend argues: "Loudness and intensity are the same thing, since a louder sound always means higher intensity." Using ideas from this chapter, explain why this statement is only partly correct.

Creative Design Challenges

7. **The Silent Auditorium Challenge:** You are asked to help design the interiors of a new school auditorium so that speech is clear from every seat, with neither an echo nor excessive reverberation. List at least four design decisions (materials, shapes, seating) you would make, and explain the physics behind each.
8. **The Noise Map:** Choose three locations you regularly spend time in (e.g., your classroom, a market, your bedroom, a bus stop). Estimate their approximate loudness in decibels using online reference values, rank them from quietest to loudest, and suggest one realistic change that could reduce noise at the loudest location.

9. **Invent an Ultrasonic Gadget:** Ultrasonic waves are already used for cleaning, welding, medical imaging, and echolocation. Design one brand-new ultrasonic gadget that doesn't exist yet, aimed at solving a problem in Indian daily life (traffic, agriculture, healthcare access, or your choice). Describe what it detects or does, and how reflected ultrasonic waves make it work.
10. **AI Creative Spark — Sound Without Ears:** Imagine designing a device that lets a person who is deaf "feel" music through touch instead of hearing. Using what you now know about amplitude, frequency, and vibration, sketch how such a device might convert sound waves into patterns of vibration on the skin.

Journey Beyond — Going Deeper

Challenge A: Measure the Speed of Sound Yourself

With a friend and a large open ground (200 m or more) — under a teacher's supervision — stand at opposite ends. Your friend bursts a balloon; you start a stopwatch the instant you *see* it burst, and stop it the instant you *hear* the pop. Repeat several times and average your readings. Measure the distance using a map app, and divide distance by average time to calculate your own experimental speed of sound. Compare it to the accepted value of about 346 m/s at 25 °C. Why did you time from "seeing" rather than from "hearing" the balloon burst on your friend's end?

Challenge B: Investigate Earphone Safety

Research what studies exist on the effects of long-term earphone and headphone use on hearing, especially among teenagers. Find out how hearing is tested, what decibel ranges define mild, moderate, and severe hearing loss, and what Indian government schemes exist for hearing aids or free cochlear implants. Write a short, evidence-based article summarising your findings for your school newsletter.

Challenge C: Why Do Concert Hall Ceilings Curve?

Research (or ask an architect, if you know one) why the ceilings and rear walls behind the stage in concert halls and conference auditoriums are often curved rather than flat. Explain, using the laws of reflection of sound, how this curved geometry helps distribute sound more evenly to the audience compared to a flat surface.

Happy Exploring! Keep listening closely — the world is speaking to you in vibrations, echoes, and frequencies you are only just learning to decode.